

RESEARCH ARTICLE

Anti-Termite Efficacy of Selected Leaf Extracts on *Pycnanthus angolensis* Wood: A Comparative Study

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ABSTRACT

Wood is widely used in construction and manufacturing but is highly prone to biodeterioration, particularly in humid tropical regions. Conventional preservatives such as chromated copper arsenate (CCA) are effective but pose environmental and health risks, creating interest in more sustainable and less hazardous alternatives. This study assessed the preservative performance of leaf extracts from *Azadirachta indica* (neem), *Chromolaena odorata* (Siam weed), and *Cedrela odorata* (Spanish cedar) on *Pycnanthus angolensis*, a non-durable Ghanaian hardwood. Extracts were prepared with ethanol and water at 5%, 10%, and 20% w/v concentrations, and untreated samples served as controls. An in-ground field test was conducted, and termite resistance was evaluated by percentage weight loss. Untreated samples recorded the highest weight loss (93%), confirming the high susceptibility of the wood. All extract treatments reduced degradation to varying degrees. Neem performed best, with an average weight loss of 79%, followed by *Chromolaena odorata* (85%) and *Cedrela odorata* (88%). Ethanol extracts were more effective than water extracts, particularly at higher concentrations, with the most notable relative reductions observed at 20%. ANOVA confirmed significant effects of leaf type, solvent, and concentration. Although the treatments resulted in only partial protection and substantial biodeterioration remained, the findings demonstrate relative improvements compared to untreated wood. Neem leaf extracts, particularly ethanol-based treatments at 20%, showed the strongest comparative performance under the conditions tested. However, the results are based on a 90-day, short-term, single-site field trial and do not assess toxicity, leachability, or long-term environmental behavior.

KEYWORDS

Durability Improvement, Biological Resistance, In-Ground Exposure, Treatment Concentration, Bio-Based Protection

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Introduction

Wood is an essential material for construction and manufacturing because of its strength, versatility, and aesthetic value (Asmara, 2025). However, its organic composition makes it highly vulnerable to biodeterioration, especially in tropical regions like Ghana where humidity accelerates termite damage.

Wood durability differs across species and depends on natural extractives such as tannins and phenolics. For example, *Tectona grandis* (Teak) is durable due to its abundant extractives (Da Costa et al., 1958), while *Pycnanthus angolensis* (Otie), a widely used hardwood, is less durable and requires treatment before use, particularly in high-risk environments (Leroy et al., 2023).

Synthetic preservatives like chromated copper arsenate (CCA) and creosote extend wood durability but pose health and environmental risks such as soil and water contamination (Changotra et al., 2024). Plant-based preservatives are increasingly considered safer and biodegradable alternatives, particularly where environmental and health concerns limit synthetic preservatives. Recent studies confirm that plant residue extracts show promise as eco-friendly wood preservatives (Li et al., 2024). Leaf extracts can offer the best source of bioactive compounds during timber processing (Han et al., 2018).

Azadirachta indica (Neem) contains azadirachtin, a compound that disrupts insects' feeding activities (Agbo et al., 2019). *Chromolaena odorata* (Siam weed) is rich in flavonoids and terpenoids, used traditionally for preservation, while *Cedrela odorata* (Spanish cedar) contains limonoids with repellent potential (Dele, 2020). Their abundance potentially makes them suitable candidates for sustainable wood preservation, subject to further validation of large-scale availability and practical extraction feasibility (Datta, 2024; Pasiecznik, 2022).

Despite their potential, research gaps remain. Neem seed extracts have been widely studied in laboratory termite tests, but leaf extracts used as wood preservatives under in-ground field conditions are less explored. Studies on *Chromolaena odorata* focus mainly on antimicrobial properties, not termite resistance on wood (Olawale et al., 2022). Similarly, research on *Cedrela odorata* emphasizes its wood's durability rather than effects of its leaf extracts as preservatives (Ruvalcaba et al., 2017). In-ground field tests, which simulate natural termite exposure, have been applied to species such as *Bambusa vulgaris* and *Azadirachta indica* (Chakurah et al., 2023; Falemara et al., 2018), but not to *Pycnanthus angolensis* with these extracts.

No study has so far compared *Azadirachta indica*, *Chromolaena odorata*, and *Cedrela odorata* leaf extracts extracted with ethanol and water at concentrations of 5%, 10%, and 20% as preservatives on *Pycnanthus angolensis* under in-ground field conditions. This study addresses this gap by objectively evaluating the anti-termite efficacy of these extracts, examining solvent and concentration effects, and identifying the most effective preservative combination. The findings aim to support sustainable wood preservation practices for timber industries especially in Ghana.

Materials and Methods

Research Design

An experimental design was used to evaluate the preservative efficacy of leaf extracts from *Azadirachta indica*, *Chromolaena odorata*, and *Cedrela odorata* on *Pycnanthus angolensis* wood. Extracts were prepared with ethanol and water as solvents at doubling concentrations of 5%, 10%, and 20% weight-to-volume (w/v). Untreated samples served as controls. Each treatment had five replicates for statistical reliability.

Wood Sampling and Preparation

Defect-free wood samples were obtained from the butt sections of three mature trees of *Pycnanthus angolensis*. Lumber sections (50 × 50 × 4000 mm) were sawn, air-dried for 14 days, and later machined at the CBT Wood Laboratory, AAMUSTED.

Specimens were machined and cut to dimensions of $12.5 \times 25 \times 250$ mm according to the modified European standard EN 252, and oven-dried at 105°C to constant weight (W1) as shown in Figure 1 and Figure 2 respectively before treatment.

Figure 1

Machining specimens



Figure 1

Oven drying samples



Plant Material Collection and Preparation

Fresh leaves of *Chromolaena odorata*, *Azadirachta indica*, and *Cedrela odorata* (Figure 3; a, b, c) respectively, were collected, thoroughly washed, and air-dried in a shaded, ventilated area. The dried leaves of *Chromolaena odorata*, *Azadirachta indica*, and *Cedrela odorata* as shown in Figure 4 (a, b, c respectively) were pounded, sieved with a 2 mm net as shown in Figure 5, blended (shown in Figure 6), and re-sieved through a $600\ \mu\text{m}$ mesh. The sieved powders were sealed in airtight zip locks for later use.

Figure 3

Fresh leaves

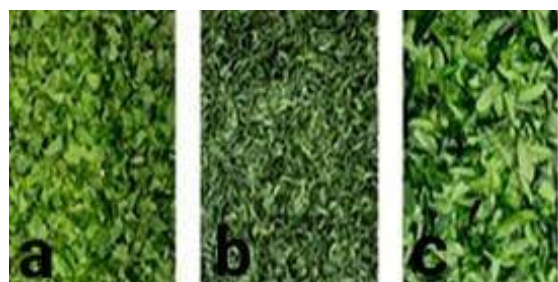


Figure 2

Dried leaves

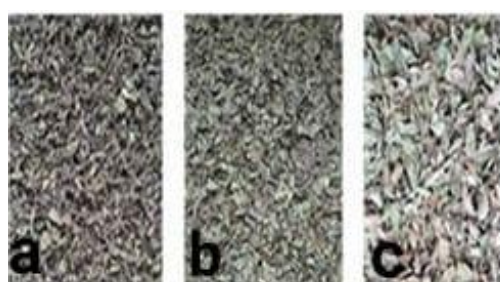


Figure 4

Pounding and sieving dried leaves



Figure 5

Blending leaves into fine powder



Extract Preparation

Extracts were prepared by maceration. Leaf powders (50 g, 100 g, and 200 g) were weighed and separately mixed with 1 L of either 95% ethanol or tap water to obtain 5%, 10%, and 20% (w/v) solutions, respectively. Ethanol was used at its supplied concentration (95%) and was not diluted, while water extracts were prepared using tap water as the solvent. The mixtures were stored in covered plastic bottles, shown in Figure 7, at room temperature and shaken manually twice daily (morning and evening) to enhance solvent-solute interaction. After five days, extracts were filtered with a clean cloth and stored in labeled plastic containers.

Figure 6

Treatments being prepared



Treatment of Wood Samples

Wood samples were soaked in the prepared extracts in covered plastic containers (Figure 8) for 48 hours using a non-pressure treatment method for surface-level protection. Retention and penetration were not measured in this study. After treatment, the samples were stacked and air-dried (Figure 9) at room temperature for 24 hours.

Figure 8

Samples soaked in plastic containers



Figure 7

Treated samples being air-dried



In-ground Field Test

Field tests were conducted on termite-active clay soil near the school field at Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Kumasi, approximately 10 m from an active termite mound. Holes were created using a 25 mm wall chisel and a 2 kg hammer (Figure 10). Wood samples were randomly buried vertically to half their length (125 mm) at 30 cm spacing as shown in Figure 11. A total of 190 wood samples were exposed for 90 days (February–April 2025). The samples comprised 180 treated specimens arranged as 3 plant species $\times$ 2 wood tissues (heartwood and sapwood) $\times$ 2 solvents $\times$ 3 concentrations $\times$ 5 replicates, plus 10 untreated control samples (5 each for heartwood and sapwood). After the exposure period, samples were retrieved, brushed to clean off soil and oven-dried at 105°C to constant weight (W2). Weight loss (%) was calculated as:

$$\text{Weight loss} = \frac{W_1 - W_2}{W_1} \times 100$$

Where W1 and W2 were initial and final oven-dry weights respectively

Figure 10

Planting samples on site

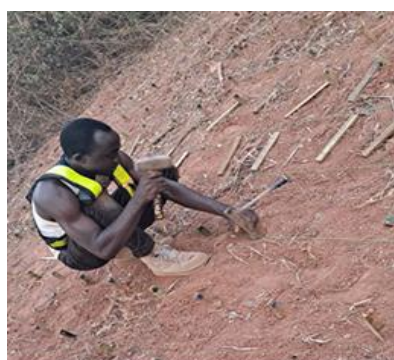


Figure 9

Test site after planting samples



Data Collection and Analysis

Weights were measured with a digital balance with a precision of 0.01 g. Data were analyzed using SPSS v.27. Means and standard deviations were calculated. ANOVA tested differences among treatments at 5% significance. Tukey's HSD post-hoc test identified pairwise differences ($p \leq 0.05$). Graphs were generated in Microsoft Excel.

Ethical Considerations

The study was conducted following guideline-based compliance in accordance with the guidelines of the Ghana Environmental Protection Agency (EPA Ghana, 2019) and the laboratory safety protocols of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED). Plant materials were collected with permission from local community authorities. Leaf quantities were limited to the minimum required for extract preparation, determined by the predefined experimental design (5%, 10%, and 20% w/v concentrations) and the total number of treatment replicates. Only healthy leaves were harvested, and collection was done in a manner that avoided damage to the parent plants.

Ethanol and other laboratory chemicals were handled using appropriate personal protective equipment, including gloves, goggles, and lab coats. Wood and extract residues were disposed of in accordance with institutional laboratory waste management procedures.

Results and Discussion

The results are based on mean weight losses of *Pycnanthus angolensis* wood treated with leaf extracts of *Azadirachta indica*, *Chromolaena odorata*, and *Cedrela odorata*, using ethanol and water at 5%, 10%, and 20% concentrations. Untreated samples (0%) served as controls. Statistical analyses (ANOVA and Tukey's HSD) were used to compare treatment effects by leaf type, solvent, and concentration.

Figure 11

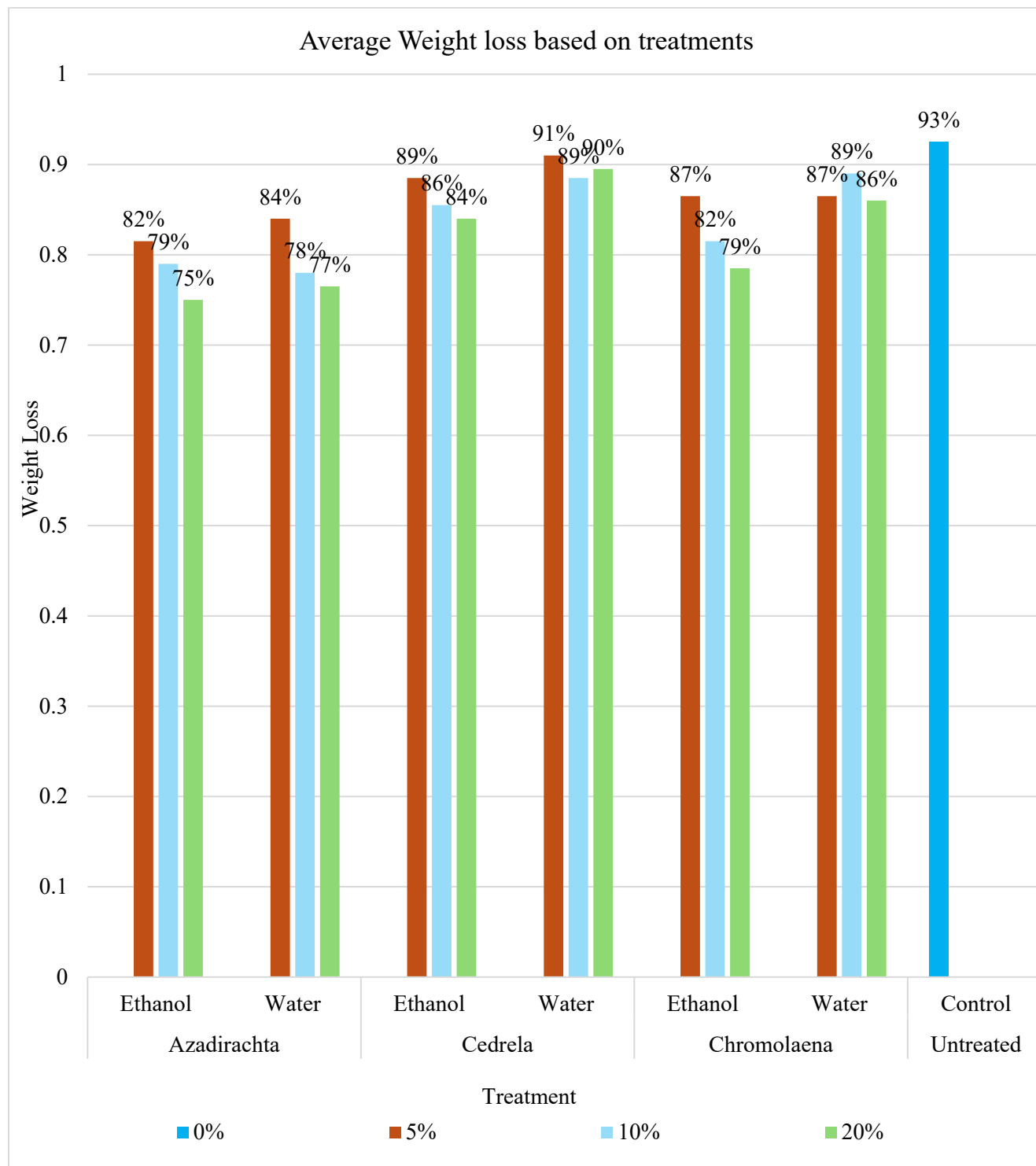
Post-Exposure Condition of Wood Samples Affected by Termites



As shown in Figure 12, untreated *Pycnanthus angolensis* wood showed severe termite damage in the in-ground test, with many galleries and frass deposits, scoring 4.5-5.0 on the damage scale (0 = no damage, 5 = complete destruction). Treated samples at 5% concentration scored around 4.5, showing little improvement. At 10%, damage dropped to about 4.0. The highest protection was at 20%, with ethanol-based *Azadirachta indica* and *Chromolaena odorata* extracts scoring around 3.5 while *Cedrela odorata* scored near 4.0. Despite reductions, treated samples still experienced substantial termite damage.

Figure 12

Average Weight Loss of Wood Samples across Treatment Types



In Figure 13, the graph shows average weight loss from the effects of *Azadirachta indica*, *Cedrela odorata*, and *Chromolaena odorata* leaf extracts on *Pycnanthus angolensis* wood. The untreated control recorded the highest weight loss (93%), confirming the high susceptibility of unprotected wood.

Across all plant extracts, increasing concentration reduced weight loss, indicating a dose-dependent preservative effect. For *Azadirachta*, ethanol extracts decreased weight loss from 82% at 5% to 75% at 20% concentration. Water extracts showed a similar trend, declining from 84% to 77% at higher concentrations. *Cedrela* also followed this pattern, with ethanol treatments reducing losses from 89% to 84%, and water treatments from 91% to 90%. *Chromolaena* in ethanol extracts reduced weight loss from 87% to 79%, while water extracts dropped from 87% to 86%.

These results demonstrate that all three species provided preservative effects, with *Azadirachta indica* showing the highest efficacy, followed by *Chromolaena odorata*, and lastly, *Cedrela odorata*. Both ethanol and water extracts were effective, though ethanol extracts generally produced slightly better results at higher concentrations.

Table 1

Descriptive Statistics of Weight Loss

Leaf Type	Solvent	Concentration	Mean	Std. Deviation
<i>Azadirachta indica</i>	Ethanol	5%	81.50%	2.121%
		10%	79.00%	1.414%
		20%	75.00%	2.828%
	Water	5%	84.00%	2.828%
		10%	78.00%	2.828%
		20%	76.50%	3.536%
<i>Cedrela odorata</i>	Ethanol	5%	88.50%	4.950%
		10%	85.50%	6.364%
		20%	84.00%	5.657%
	Water	5%	91.00%	5.657%
		10%	88.50%	7.778%
		20%	89.50%	2.121%
<i>Chromolaena odorata</i>	Ethanol	5%	86.50%	4.950%
		10%	81.50%	3.536%
		20%	78.50%	3.536%
	Water	5%	86.50%	2.121%
		10%	89.00%	2.828%
		20%	86.00%	1.414%

As shown in Table 1, descriptive statistics showed that the untreated control samples had the highest mean weight loss (92.5%), confirming the high susceptibility of *Pycnanthus angolensis* to termite damage. All plant extracts reduced weight loss to varying degrees. Among species, *Azadirachta indica* performed best, with mean losses at 79%, followed by *Chromolaena odorata* at 85% and *Cedrela odorata*, 88%.

When grouped by solvents, ethanol extracts were generally more effective than water extracts. Ethanol treatments reduced mean weight loss from about 85% at 5% concentration to 79% at 20%, while water extracts showed a smaller improvement, from about 87% to 84% across the same range.

Across all treatments, the 20% concentration produced lower weight losses compared to the 5% and 10% concentrations.

Table I*Tests of Between-Subjects Effects*

Source	Sum of Squares	Mean Square	F	p
Corrected Model	950.316 ^a	52.795	3.082	.010
Intercept	199665.818	199665.818	11654.840	< .001
Leaf Type * Solvent * Concentration	34.111	8.528	.498	.738
Leaf Type * Solvent	24.889	12.444	.726	.497
Leaf Type * Concentration	23.333	5.833	.341	.847
Solvent * Concentration	15.056	7.528	.439	.651
Leaf Type	480.667	240.333	14.029	< .001
Solvent	93.444	93.444	5.455	.031
Concentration	136.500	68.250	3.984	.036

Table 2 shows the between-subjects effects of treatments. Leaf type had a strong effect on weight loss ($F = 14.029$, $p < .001$), showing that the choice of plant species significantly influenced wood weight loss. Solvent was also effective ($F = 5.455$, $p = .031$), with ethanol extracts generally reducing weight loss more effectively than water extracts. Concentration was also effective ($F = 3.984$, $p = .036$).

In contrast, none of the interaction terms were significant. The three-way interaction of leaf type $\times$ solvent $\times$ concentration ($F = 0.498$, $p = .738$), and the two-way interactions (leaf $\times$ solvent, $F = 0.726$, $p = .497$; leaf $\times$ concentration, $F = 0.341$, $p = .847$; solvent $\times$ concentration, $F = 0.439$, $p = .651$) all failed to reach significance. This means the extracts' effects were driven by the independent factors of leaf type, solvent, and concentration, rather than by combined or synergistic effects among them.

Table 3*Multiple Comparisons of Leaf Type Effects*

Leaf Type	Mean Difference	Std. Error	p
<i>Azadirachta indica</i> vs. <i>Cedrela odorata</i>	8.83%*	1.690%	< .001
<i>Azadirachta indica</i> vs. <i>Chromolaena odorata</i>	5.67%*	1.690%	.016
<i>Cedrela odorata</i> vs. <i>Chromolaena odorata</i>	3.17%	1.690%	.272
Control vs. <i>Azadirachta indica</i>	13.50%*	3.161%	.002
Control vs. <i>Cedrela odorata</i>	4.67%	3.161%	.470
Control vs. <i>Chromolaena odorata</i>	7.83%	3.161%	.096

As shown in Table 3, post-hoc analysis using Tukey's HSD confirmed that leaf type significantly influenced wood weight loss. *Azadirachta indica* treatments consistently outperformed the others, with significantly lower mean losses compared to *Cedrela odorata* (8.83%, $p < .001$), *Chromolaena odorata* (5.67%, $p = .016$), and the untreated control (13.50%, $p = .002$). In contrast, no significant differences were found between *Cedrela* and *Chromolaena*, or between either species and the control, indicating that their preservative effects were not as strong compared to *Azadirachta*.

Table 4*Multiple Comparisons of Solvent Effects*

Solvent	Mean Difference	Std. Error	p
Ethanol vs. Control	10.28%*	3.085%	.009
Water vs. Control	7.06%	3.085%	.082
Ethanol vs. Water	3.22%	1.380%	.075

Post-hoc comparisons showed that ethanol extracts significantly reduced mean weight loss compared to the untreated control (-10.28%, $p = .009$). However, the difference between ethanol and water extracts was not statistically significant (-3.22%, $p = .075$). Likewise, water extracts did not differ significantly from the control (+7.06%, $p = .082$), suggesting that ethanol was the more effective solvent for extracting preservative compounds as shown in Table 4.

Table 5

Multiple Comparisons of Concentration Effects

<i>Concentration</i>	<i>Mean Difference</i>	<i>Std. Error</i>	<i>p</i>
0% vs. 5%	6.17%	3.161%	.241
0% vs. 10%	8.92%*	3.161%	.049
0% vs. 20%	10.92%*	3.161%	.013
5% vs. 10%	2.75%	1.690%	.388
5% vs. 20%	4.75%	1.690%	.050
10% vs. 20%	2.00%	1.690%	.644

Post-hoc comparisons showed that higher extract concentrations generally reduced wood weight loss. The untreated control (0%) had significantly greater losses than both the 10% (8.92%, $p = .049$) and 20% treatments (10.92%, $p = .013$), but not the 5% level ($p = .241$). Among treated samples, differences were less distinct, though a borderline reduction was observed between 5% and 20% (4.75%, $p = .050$). No significant differences emerged between 5% and 10% or between 10% and 20%. These results indicate that increasing concentration improves protection, with 20% offering the strongest effect as shown in Table 5.

The untreated control samples recorded the highest mean weight loss (92.5%), confirming the high susceptibility of *Pycnanthus angolensis* to termite attack. This agrees with reports that classify the species as non-durable under tropical field conditions (Udeozo et al., 2015).

All plant extract treatments reduced weight loss relative to the control, although protection levels varied among species. *Azadirachta indica* showed the strongest performance, with average losses of about 79%, significantly lower than *Chromolaena odorata* (85%) and *Cedrela odorata* (88%). This aligns with evidence attributing neem's insecticidal and antifeedant activity to azadirachtin and related limonoids (Adusei & Azupio, 2022; Sinha & Ray, 2024).

The comparatively weaker performance of *Chromolaena odorata* and *Cedrela odorata* likely reflects differences in extractive composition and bioactivity. *Chromolaena odorata* contains phenolics and flavonoids, but its termite resistance is often described as moderate (Budha et al., 2023). *Cedrela odorata* extracts have been more frequently associated with antifungal rather than anti-termite effects (Dele, 2020).

Solvent type influenced preservative performance, with ethanol extracts consistently reducing weight loss more than water extracts. Weight loss declined from approximately 85% at 5% concentration to 79% at 20% for ethanol treatments, supporting evidence that ethanol enhances extraction of insect-deterrent compounds (Broda & Mazela, 2020; Kirker et al., 2024). Increasing extract concentration further improved performance, confirming a dose-dependent response (Asiry et al., 2022). However, changes beyond 10% were modest, likely due to limited penetration under non-pressure treatment.

Overall, ethanol-based neem leaf extracts reduced termite damage providing partial protection, indicating, indicating their potential as supplementary, low-hazard alternatives rather than direct replacements for synthetic preservatives in severe termite eCalovi et al., 2024; Ong et al., 2025).

Leaf type ($F = 14.03$, $p < .001$), solvent ($F = 5.46$, $p = .031$), and concentration ($F = 3.98$, $p = .036$) each had significant main effects, while none of the interaction terms were significant. This indicates that each factor independently influenced wood durability, with no strong effects from the combination among them.

Conclusions

The study demonstrates that leaf extracts from *Azadirachta indica*, *Chromolaena odorata*, and *Cedrela odorata* can reduce termite damage in *Pycnanthus angolensis*, though effectiveness varied by leaf type, solvent, and concentration. Neem extracts, particularly ethanol-based treatments at 20%, produced the greatest reduction in weight loss. The research was limited by its 90-day duration, which may not reflect long-term durability in varying tropical conditions. It evaluated only *Pycnanthus angolensis* wood, restricting applicability to other Ghanaian hardwoods. Additionally, field tests at a single site may not account for diverse soil types, climates, or termite species distributions.

However, these findings reinforce the potential of locally available plant extracts as eco-friendly wood preservatives. Further research could include long-term trials to assess extract durability and efficacy. Testing concentrations above 20% could establish optimum performance. Repeating tests across different climates and soils can optimise extract use.

These findings highlight *Azadirachta indica* as the best-performing among the tested extracts. Ethanol-based extracts, especially at 20% concentration, provided the most reliable protection. Water extracts showed only limited effectiveness, but could still be useful in rural or resource-limited settings where ethanol is less accessible.

At the policy level, these results provide evidence to support the development of plant-based preservation strategies within Ghana's forestry sector. Incorporating such bio-preservatives into national timber treatment guidelines could reduce reliance on hazardous chemicals, promoting both environmental safety and sustainable resource use.

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Author Contribution Statement

Conceptualisation: KA (lead), MDM (equal)

Data Curation: MDM (lead)

Formal Analysis: MDM (lead), KA (equal), SSU (supporting)

Methodology: MDM (lead)

Validation: KA (lead), FKB (equal), MBD (supporting)

Writing – Original Draft: KA (lead), MDM (supporting)

Supervision: KA (lead), FKB (supporting), MBD (supporting)

AI Disclosure Statement

The authors used *ChatGPT (OpenAI)* to assist in language editing to improve readability and also revised the abstract to meet journal requirements in word count. The authors reviewed all generated content carefully and take full responsibility for the accuracy and integrity of the final manuscript.

References

- Adusei, S., & Azupio, S. (2022). Neem: A novel biocide for pest and disease control of plants. *Journal of Chemistry*, 2022(1), 6778554. <https://doi.org/10.1155/2022/6778554>
- Agbo, B. E., Nta, A. I., & Ajaba, M. O. (2019). Bio-pesticidal properties of neem (*Azadirachta indica*). *Advances in Trends in Agricultural Sciences*, 1, 17–26.
- Asiry, K. A., Al-Nasser, A. S., & Abohassan, R. A. (2022). Repellent and toxic effects of some plant extracts on subterranean termite *Psammotermes hybostoma*. *International Journal of Agriculture & Biology*, 27(2), 99–104. <https://doi.org/10.17957/IJAB/15.1905>
- Asmara, Y. P. (2025). *Green engineering materials: Innovations and applications for sustainable construction*. CRC Press.
- Broda, M. (2020). Natural compounds for wood protection against fungi—A review. *Molecules*, 25(15), 3538. <https://doi.org/10.3390/molecules25153538>
- Budha Magar, A., Shrestha, D., Pakka, S., & Sharma, K. R. (2023). Phytochemistry, biological, and toxicity study on aqueous and methanol extracts of *Chromolaena odorata*. *The Scientific World Journal*, 2023(1), 6689271. <https://doi.org/10.1155/2023/6689271>
- Calovi, M., Zanardi, A., & Rossi, S. (2024). Recent advances in bio-based wood protective systems: A comprehensive review. *Applied Sciences*, 14(2), 736. <https://doi.org/10.3390/app14020736>
- Chakurah, I., Bih, F. K., & Antwi, K. (2023). Resistance to termite attack properties of *Azadirachta indica* wood from the Savannah ecological zone of Ghana. *International Journal of Innovative Science and Research Technology*, 8(9), 263–268.
- Changotra, R., Rajput, H., & Dhir, A. (2024). Environmental impact of chemical wood preservatives: A review. *Environmental Science and Pollution Research*, 31(5), 7890–7905. <https://doi.org/10.1007/s11356-023-31234-5>
- Da Costa, E. W. B., Rudman, P., & Gay, F. J. (1958). Investigations on the durability of *Tectona grandis*. *Empire Forestry Review*, 291–298.
- Datta, H. S. (2024). Harnessing neem (*Azadirachta indica* A. Juss): A sustainable approach to natural farming. *International Journal of Plant & Soil Science*, 36(7), 643–648. <http://journal.repositoryarticle.com/id/eprint/1421/>
- Dele, A. (2020). Volatile oils from *Cedrela odorata* L. as protectants against *Sitophilus zeamais* (Coleoptera: Curculionidae). *American Journal of Essential Oils and Natural Products*, 8, 20–24.
- Eaton, R. A., & Hale, M. D. C. (1993). *Wood: Decay, pests, and protection*. Chapman and Hall.

- Environmental Protection Agency, Ghana. (2019). *Environment and health protection—Requirements for ambient air quality and point source/stack emissions* (Standard 1236 of 2019). Author.
- European Committee for Standardization. (2014). *Field test method for determining the relative protective effectiveness of a wood preservative in ground contact* (EN 252:2014). Author.
- Falemara, B. C., Ajayi, B., Kambai, C., & Ukanyirioha, C. (2018). Durability assessment of cashew nut shell liquid on *Bambusa vulgaris* schrad in timber graveyard test. In *Emerging issues in sustainable forest management: Experiences and lessons for Nigeria. Proceedings of the 40th Annual Conference of the Forestry Association of Nigeria* (pp. 206–213).
- Ghaffariyan, M. R. (2023). Utilization of forest biomass residues for bioenergy and bioproducts. *Bioresource Technology Reports*, 22, 101432. <https://doi.org/10.1016/j.biteb.2023.101432>
- Goodell, B., & Nielsen, G. (2023). Wood biodeterioration. In *Springer handbook of wood science and technology* (pp. 139–177). Springer International Publishing.
- Han, H. S., Jacobson, A., Bilek, E. T., & Sessions, J. (2018). Waste to wisdom: Utilizing forest residues for the production of bioenergy and biobased products. *Applied Engineering in Agriculture*, 34(1), 5–10.
- Kirker, G. T., Hassan, B., Mankowski, M. E., & Eller, F. J. (2024). Critical review on the use of extractives of naturally durable woods as natural wood protectants. *Insects*, 15(1), 69. <https://doi.org/10.3390/insects15010069>
- Lebow, S. T., Lebow, P. K., Foster, D. O., & Brooks, K. M. (2000). *Environmental impact of preservative-treated wood in a wetland boardwalk* (Vol. 582). US Department of Agriculture, Forest Service, Forest Products Laboratory.
- Leroy, M., Candelier, K., Damay, J., Bossu, J., Lehnebach, R., Thévenon, M. F., ... Clair, B. (2023). Natural durability of 8 tropical species suitable for structural roundwood: Laboratory screening tests for resistance to fungi and termites. *Bois et Forêts des Tropiques*, 358, 15–29. <https://hal.science/hal-04504833/>
- Li, K., Huang, D., Gao, X., He, J., Sun, X., & Yan, L. (2024). Potential applications for eco-friendly wood preservative of the extracts of thermally degraded cobs and stalks of corn. *European Journal of Wood and Wood Products*, 82(4), 1133–1143. <https://doi.org/10.1007/s00107-024-02072-4>
- Mahalle, D., & Gupta, A. (2021). Estimation of total phenol, flavonoids and alkaloid content and evaluation of antioxidant and antimicrobial activity of *Tinospora crispa* leaves and flower extracts. *Journal of Advanced Scientific Research*, 12(1), 208-212
- Olawale, F., Olofinisan, K., & Iwaloye, O. (2022). Biological activities of *Chromolaena odorata*: A mechanistic review. *South African Journal of Botany*, 144, 44–57. <https://doi.org/10.1016/j.sajb.2021.09.001>
- Ong, Z., Arip, M., Nasir, M., & Lee, H. L. (2025). Advances in wood preservation technology: A review of conventional and nanotechnology preservation approaches. *BioResources*, 20(3). <https://doi.org/10.15376/biores.20.3.Ong>
- Pasiecznik, N. M. (2022). *Cedrela odorata* (Spanish cedar). *CABI Compendium*. <https://doi.org/10.1079/fc.11975.20210114102>

- Ruvalcaba, L. P., Armenta, K. G. M., Valdés, T. D., de Jesús Velázquez Alcaraz, T., Tafoya, F. A., López, R. M., & Juárez, M. G. Y. (2017). Effect of cedar extract (*Cedrela odorata* L.) on the termite (*Reticulitermes* spp.). *Agricultural Sciences*, 8, 261–266.
- Sinha, N., & Ray, S. (2024). Different extraction processes of neem (*Azadirachta indica*) and its potential in controlling pest populations. *Journal of Entomology and Zoology Studies*, 12(4), 18–26. <https://doi.org/10.22271/j.ento.2024.v12.i4a.9345>
- Thomas, M., Gayathri, S., Athira, K. P., Elias, R. S., Soumya, S., & Kurian, P. (2023). Efficacy of plant leaf extracts on termites under laboratory conditions. *Journal of Entomology and Zoology Studies*, 11(1), 106–110. <https://doi.org/10.22271/j.ento.2023.v11.i1b.9131>
- Udeozo, I. P., Ejikeme, C. M., Eboatu, A. N., & Arinze, R. U. (2015). The efficacy of *Pycnanthus angolensis* timber: An assay of its properties and chemical constituents. *Global Journal of Biotechnology & Biochemistry*, 10(3), 121–125.